

1. **Project Name:** High energy Density Coating of High Temperature Advanced Materials for Energy Efficient Performance
2. **Lead Organization:**
 - 1) Department of Materials Science & Engineering
University of Tennessee
10521 Research Dr., Suit 400, Knoxville, TN 37932
 - 2) Materials Processing Group, Metals and Ceramics Division
Oak Ridge National Laboratory
P.O. Box 2008, Oak Ridge, TN 37831
3. **Principal Investigator:**
 - Narendra B. Dahotre, (865)974-0523 (T)/(865)974-0530 (F)
Email: ndahotre@utk.edu
 - Vinod K. Sikka, (865)574-5112 (T)/(865)574-4357 (F)
Email: sikkavk@ornl.gov
4. **Project Partners:**
 - Cummins Engine Company, Inc., **In-Kind**, supply and evaluate test coupons and prototype components for processing by proposed method
Contact: Paul C. Becker, Director, Metallurgical Services; Ph: (812) 377-5000
 - STOODY, **In-kind**, provide background and experience related to weld overlay problems in steel, power industries, provide weld overlay coupons for coating, evaluate the overlaid samples
Contact: Ravi Menon, VP Technology, Ph: (502) 781-9777, Fax: (502) 843-4228
 - Hydro Resources Solutions, LLC , **In-kind**, provide guidance and consultations on currently used materials for hydroelectric energy generation, provide prototype turbine parts, conduct cavitation erosion tests
Contact: Patrick A. March, General Manager, Ph: (865) 599-6437
Email: pamarch@tva.com
 - Applied Thermal Coating, **In-Kind**, identify areas for corrosion and wear in power, chemical and paper industries, provide test coupons, test coupons
Contact: Harley Grant, President, Ph: (423) 267-0647, Fax: (423)267-0637
 - Weyerhaeuser, **In-kind**, provide guidance and consultation on currently used refractory materials, provide refractory materials for coating, conduct corrosion tests,
Contact: J Peter Gorog, Senior Engineering Advisor, Energy & Recovery R&D
Ph: (253) 924-6514, Email: peter.gorog@weyerhaeuser.com
5. **Date Project Initiated and FY of Effort:** 8/1/2001 and Fiscal year 3
6. **Expected Completion Date:** 12/31/2004
(No cost extension for the period of 1/1/04-12/31/04)

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** The objective of the project is to process coatings with superior wear and oxidation resistance on low cost steels using high energy density heating techniques such as a UV laser and an Infrared Lamp. Such coatings will enable achievement of improved energy efficiency.
8. **Technical Barrier(s) Being Addressed:** The metal materials with enhanced surfaces for wear and corrosion resistance will have cross cutting applications in most of the industrial production sector in United States. Applications include: hydro turbines, combustion chambers in diesel engines, die casting dies and inserts, continuous steel casting rolls, transfer rolls for flat glass, heat exchangers, cutting and casting tools, components for chemical processes, components for processing of pulp and paper, and auto engines, etc. In these applications, however, these materials often experience extreme mechanical, thermal and chemical loading conditions and are expected to perform effectively beyond existing limits. The existing limits of performance for these materials can only be extended via surface enhancement technology, which presently appears to be the most suitable technical and economic approach. Also surface modification allows conversion of inexpensive substrate material for high performance applications without using very expensive bulk alloys. Thus there is a critical need to develop a more suitable and reliable surface modification technique(s).

Existing surface modification techniques based on coating (physical vapor deposition, chemical vapor deposition, thermal spray, etc.) are either prohibitively time consuming and expensive or produce coatings with physical and chemical nature that restrict their use for limited number of applications. When these methods are successful in producing reasonably sound coatings, they are seldom able to withstand the intended high service temperatures ($> 500^{\circ}\text{C}$). On the contrary, the research outlined in this proposal promotes the synthesis of strong modified surfaces and significantly improve the life of hybrid components for wear and corrosion applications. This is due to the fact that laser and plasma infrared operating parameters can be precisely controlled, thereby generating thermal conditions sufficient to synthesize/fabricate a product within the surface and subsurface region of the substrate material while producing both a minimum reaction zone and minimum impact on the microstructure within the substrate. The technique through the control on and combination of the processing parameters can also be used to tailor the microstructure in and around the interface region between the modified surface and the substrate.

9. **Project Pathway:** The major goal of the project is to develop a reliable, efficient and economic method of coating ceramic on metal using high energy density based technique. The development is conducted for FeAl as coating ferrous (steels) systems. The process and coating-substrate material systems will be optimized to suit specific industrial applications

The efforts will also be based on characterization of processed coating-substrate material systems for wear and corrosion properties under various conditions. The correlation between coating properties and process parameters are being established.

The major efforts of the proposed research program are:

- To understand the chemical, physical and microstructural transformations taking place in the selected representative systems during high energy density treatment. This knowledge about various transformations is believed to be necessary to subsequently develop highly efficient and cost-effective customized applications for the surface protection/modification.
- Development of the technique for modifying the surfaces of various surface geometries and materials for enhanced wear and corrosion properties in real components.

10. **Critical Technical Metrics:** The milestones/deliverables schedule for the project, both completed and planned are as following

| Description | Completed Date | Planned Completion Date |
|--|--|---|
| <ul style="list-style-type: none"> • Laser Coating Experiments • IR Coating Experiments • Microstructural Analysis • Mechanical Testing Hardness Testing Wear Testing • Corrosion/Oxidation Testing • Integrated IR/Laser Trials for Coating • Modeling Based on Microstructural Analysis • Coating of Industrial Components • Industrial Trials of Coated Components | June 2002 July 2002 Continues December 2002 December 2002 Continues August 2003 Continues Continues Continues | June 2002 July 2003 September 2004 December 2002 December 2002 September 2004 August 2003 October 2004 August 2004 November 2004 |

PROJECT PLANS AND PROGRESS

11. Past Accomplishments:

- Intermetallic FeAl coatings have been successfully processed on 4340 steel using **laser** and **IR-based** techniques.
- Composite coatings (hard ceramic particles in steel matrix) have been successfully processed using **IR** and with limited success by **lasers**.
- Microstructural characterization using optical and scanning electron microscopies has been performed.
- Identification and characterization of phases within coating using x-ray diffraction and EDS has been performed.
- FeAl and composite coatings are characterized for mechanical properties using microhardness and dry sliding block-on-disk wear tests.
- Both coatings provided high hardness (> 2 fold) and wear resistance compared to the substrate material (4340 steel)
- Fe-Al coatings on 4340 steel synthesized using laser technique indicated several fold increase in high temperature (600C) oxidation resistance

12. Future Plans:

- Elevated temperature oxidation studies will be continued on the coatings.
- Thermodynamic model of phase evolution during coating is attempted and will continue further (schedule is provided in item 8)
- Coatings of limited number and types of industrial components will be performed and they will be tested in industrial applications (schedule is provided in item 8)
- If time and resources permit, transmission microscopy work will be performed on the coatings to further understand the phase evolution behavior. This work will continue until the end of the project.

- Addition high temperature oxidation studies on the coatings will be conducted at 3 more temperatures (400, 800, and 1000C)

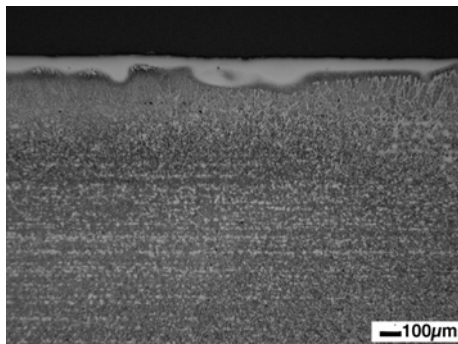
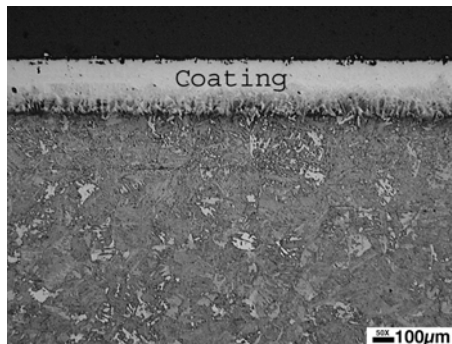
13. **Project Changes:** In the original proposal it was proposed that boride and carbide based coatings will be synthesized. However, after initial efforts by the end of first year it was found that iron-aluminum (aluminide) coatings are possible to be synthesized via proposed high energy technique and such aluminide coatings would be more suited for high temperature applications. Therefore for the remaining duration of the project efforts continued on synthesis and characterization of aluminide coatings. Also, an emphasis on TEM studies of these coatings was introduced which is important to understand phase evolution during reaction of formation of these coatings and their stoichiometries that are critical to high temperature performance. In view of these changes, last year one-year no-cost extension for the project was obtained.

14. **Commercialization Potential, Plans and Activities:**

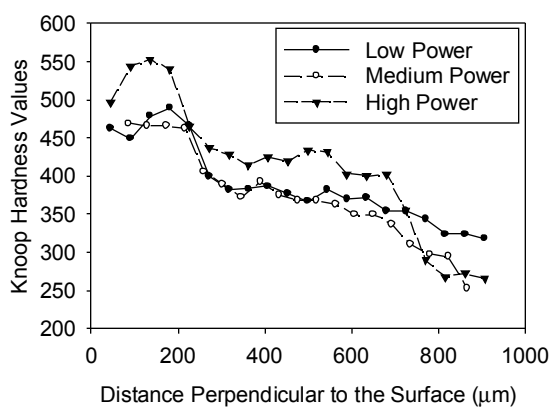
- The major product of this research efforts will be coatings for wear and oxidation resistance
- The secondary product of this research efforts will be a technique (laser and IR based) to produce these coatings
- Due to participation of 5 industrial organizations from various sectors it is expected that these participants will identify applications for these coatings and coating techniques.

15. **Patents, publications, presentations:**

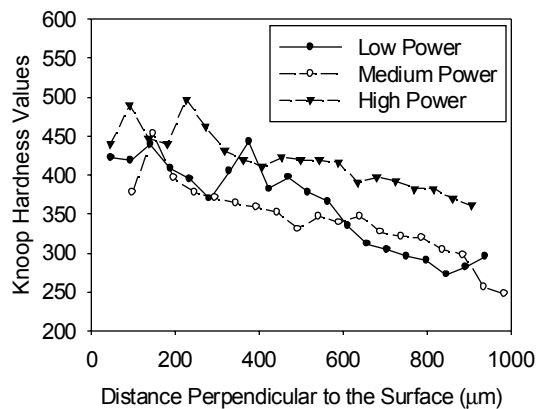
1. **Laser Assisted Surface Modification of 4340 Steel with Iron-Aluminum Alloys**, G.Muralidharan, P.G. Engleman, C.A. Blue, V.K. Sikka, A.K.Singh, A. Khangar, and N.B. Dahotre, in **Surface Engineering 2002—Synthesis, Characterization and Applications**, MRS Proceedings Volume 750, Editors: A. Kumar, W.J. Meng, Y-T. Cheng, J. Zabinski, G.L. Doll, S. Veprék.
2. **Laser Surface Engineered Iron-Aluminum Coatings**, 2002 MRS Fall Meeting, Boston, MA., oral presentation.

16. (OPTIONAL) Highlight:**Results Achieved:****Laser****IR**

1. Continuous, defect-free coatings based on FeAl, a material with good oxidation resistance, have been processed using UV- laser, and the IR Lamp.

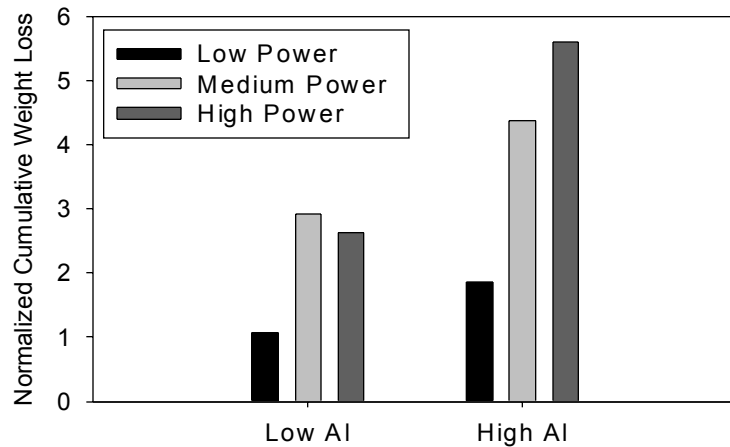


(a)

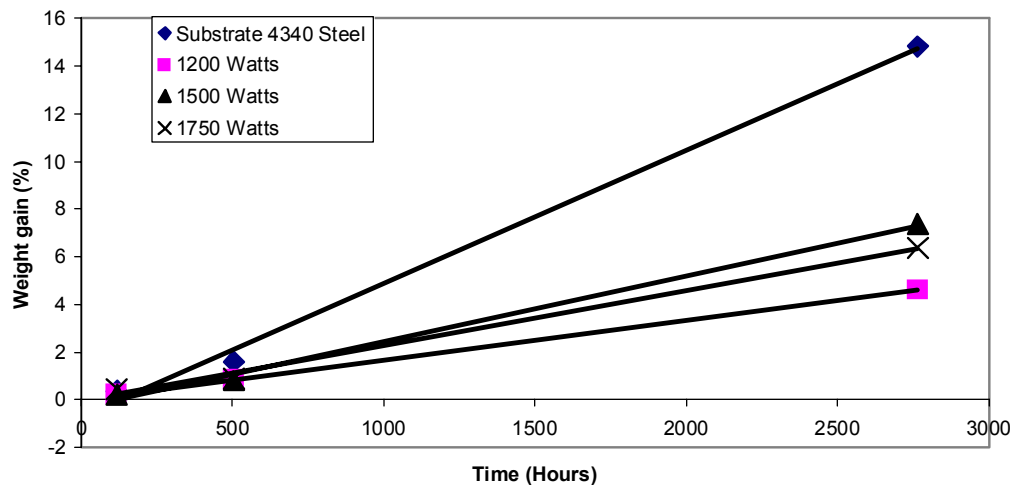


(b)

2. Enhanced microhardness in laser processed as a function of distance perpendicular to the surface in coatings prepared with (a) Precursor layer with 43.5 mole %Al, and (b) Precursor layer with 75 mole % Al.



3. Enhanced wear resistance in laser processed as a function of distance perpendicular to the surface in coatings prepared with (a) Precursor layer with 43.5 mole %Al, and (b) Precursor layer with 75 mole % Al.



4. Improved oxidation resistant in Fe-Al coated 4340 steel using laser-based technique.

Significance to IOF:

Both coatings of FeAl and carbides are of great importance and interest to many of the IOFs. The FeAl coatings are useful for oxidation and sulfidation resistance and carbides for wear resistance. These coatings would benefit chemical, mining, and pulp and paper IOF. Energy and cost savings will result from improved corrosion/oxidation and wear resistance through these coatings.